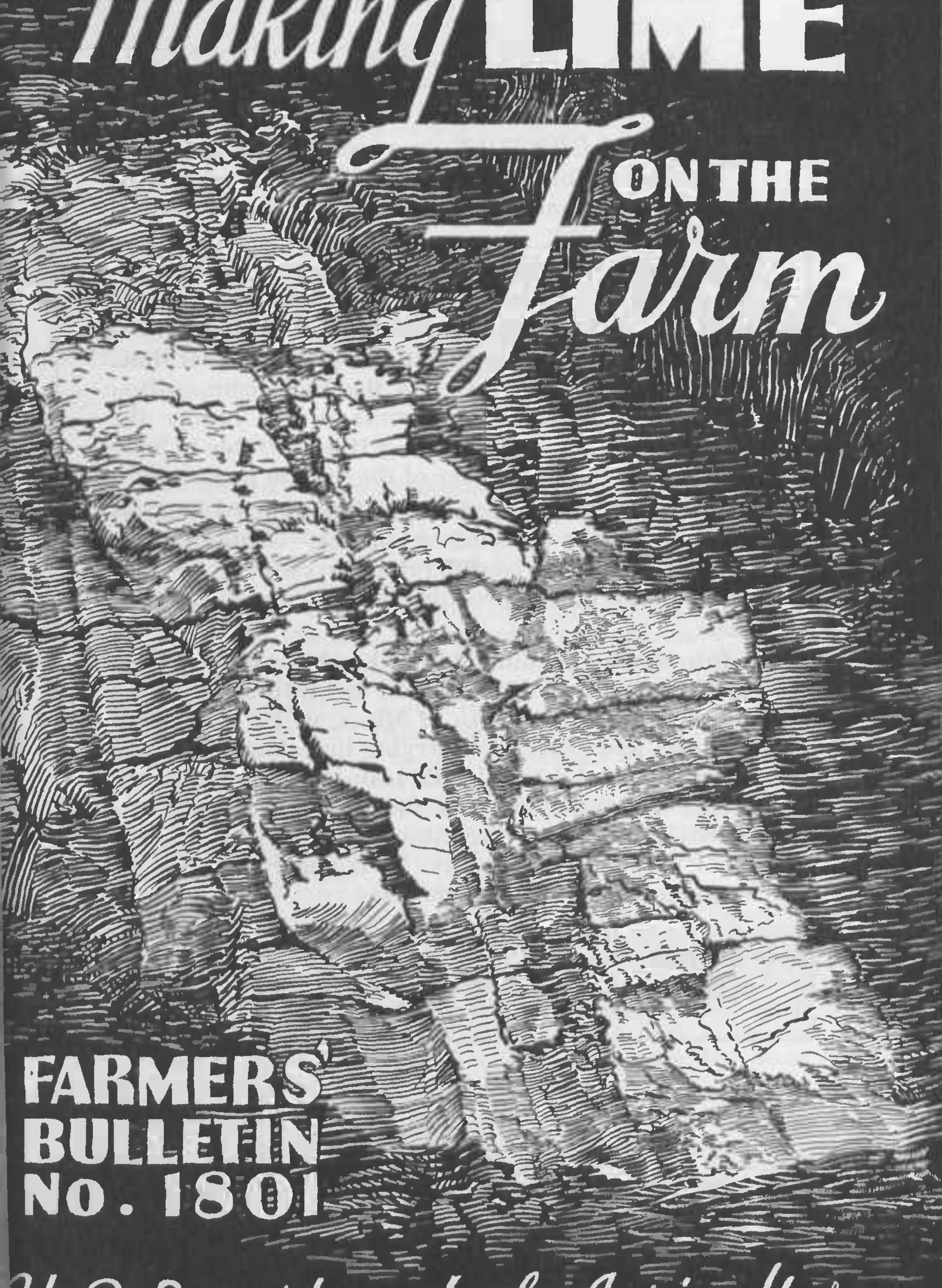
Making LIME ON THE Farm



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WHERE LIMESTONE is readily available it is often feasible for farmers, either individually or in groups, to quarry and burn or grind the stone for use on their land.

Limestone is sometimes almost pure calcium carbonate, but often it contains varying amounts of other materials. Before undertaking to develop a limestone quarry for the production of agricultural lime, the extent of the supply and the exact composition of the stone should be determined. To reduce the labor of hauling and spreading, it is desirable to have the quarry near the center of the area to be served.

Limestone may be reduced to the required fineness for use either by grinding or burning. Grinding limestone requires a considerable investment in machinery, and burning requires an abundance of cheap fuel.

Information in this bulletin has been drawn from various sources. Among them are Information Circular 6603 of the Bureau of Mines, which deals with methods and costs of quarrying limestone; Blaster's Handbook, published by E. I. du Pont de Nemours & Co.; and publications of the United States Bureau of Standards, and the State Agricultural Experiment Stations of Kentucky, Michigan, Pennsylvania, Virginia, and West Virginia.

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MAKING LIME ON THE FARM

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INTRODUCTION

THE USE OF LIME for sweetening acid soils is almost a universal practice in humid regions. It is one of the big three—"lime, legumes, and livestock"—so effectively used in building and conserving soil fertility.[1] But the need for lime has never been met fully. To maintain proper amounts in the soils, it is estimated that the annual lime requirement of American farms would be about 32,000,000 tons, or 24 times the amount sold by commercial concerns in 1933. Fortunately, lime is one of the most common of all materials, occurring in nature as limestone, marl, marble, coral, oyster shells, and clamshells and in other forms.

The farmer can buy lime from commercial sources in the form and degree of purity desired; he can produce his own if he has a convenient supply of raw material; or he can cooperate with his neighbors in working a deposit. This bulletin deals with factors which should be considered by a farmer or a group of farmers before investing in equipment for obtaining lime from limestone or marl.

LIMESTONE

Limestone is usually found in more or less horizontal beds varying as to composition, hardness, weight, and weathering. Often it is so hard that explosives must be used to break it up, but sometimes it is so broken down by weathering that it can be removed with pick and shovel. It varies in color from light gray to dark brown or black. It is sometimes almost pure calcium carbonate, but some deposits contain magnesium carbonate in varying amounts.

LOCAL DEMAND

In the case of a farmers' cooperative quarry, or a private enterprise, the quantity of limestone which can be placed at a fair price

[1] See Farmers' Bulletin 921, The Principles of the Liming of Soils.

in the locality is an important consideration, since the output needed determines the size and type of equipment to be used. Usually some information is to be found on the quantity of lime shipped into the area annually, and this figure can be checked against the recommendations of the county agent or the State agricultural college as to the requirements of the district. These requirements vary with the soils, but a rate commonly recommended is 1 ton per acre. In some sections fine limestone or lime is applied annually at rates of from 200 to 300 pounds per acre by means of fertilizer attachments on seed drills. Recommendations differ also as to the fineness of the limestone. Some soils respond satisfactorily to a ground limestone that passes a 10-mesh screen, whereas others react better to a finer stone.

The price of lime varies with location, quality, and fineness of grinding and may be anywhere from 80 cents a ton at the quarry to $5 or more for delivered, finely ground material.

For the farm quarry the geographical limit of the probable market is usually fixed by the cost of hauling, generally by trucks. Sometimes the lime is spread directly on the field from the delivery truck. In Indiana and Illinois the ton-mile rate for hauling ranged from 3 to 10 cents and the spreading cost from 25 to 50 cents a ton. A commercial trucker in Indiana charges 35 cents a ton for distances up to 5 miles, 5 cents a ton-mile for each additional mile up to 20 miles, and 4 cents a ton-mile for distances beyond 20 miles.

THE QUARRY

Of primary importance in any lime-production operation is the quantity and quality of the available limestone. The individual farmer, perhaps, is not so much interested in the extent of his supply as he is in its quality, but a group of farmers should satisfy themselves that there is sufficient quantity before building a plant. A close estimate of the available material can be made by boring, probing, and digging. Some estimate of the thickness of the deposit can be made by examining exposed outcroppings, but drilling is the surest method, although expensive for small operations. The area of the formation in square feet, multiplied by the depth of the deposit, also in feet, will give the volume, and this figure multiplied by 168, the average weight of a cubic foot of limestone, will give the approximate weight of the deposit.

It is not uncommon for a farmer to rent or lease a quarry site, or for a number of farmers to do, as individuals, the work necessary to get out lime for their own needs from one quarry site. In such cases, a stipulated price is paid for each ton of rock taken from the quarry. The price is a matter of bargaining, but in a number of cases has varied from 2 to 5 cents a ton.

The quality of the limestone should be accurately determined before any funds are expended. Samples taken so as to be representative of the formation, should be analyzed by a chemist to determine the calcium carbonate equivalent. Rock containing 80 percent or more of calcium carbonate is good enough to warrant further investigation, but with less than that the advisability of proceeding further should be carefully considered. Larger quantities of low-

grade than of high-grade stone must be used to obtain good results, and the labor in hauling and spreading is likewise greater. The more overburden, or material covering the deposit, the greater the cost of getting out the stone. For farm quarries, 3 feet is probably the maximum allowable overburden.

If there is a choice of locations, the quarry should be near the center of the area where the lime is to be applied; and it is desirable to have a good, firm road with easy grades leading from it. A good road out to a paved highway is almost a necessity for a neighborhood quarry.

STRIPPING

The removal of overburden is not usually a large operation on farm quarries. Where the job is not large, it is usually done with a drag scraper pulled by a team or tractor. Usually such work can be done with farm labor and equipment, with little cash expenditure; but if it is done by contract, the cost will vary from 15 to 50 cents a cubic yard of earth. For large operations fresno scrapers or power shovels are used but such heavy equipment is not adapted to the ordinary farm quarry.

DRILLING

In many cases the upper strata of the formation are weathered to such a degree that quarrying can be done by hand. Where the strata of stone are not clearly defined, are thick, or only slightly weathered, drilling and blasting will be necessary. Drilling may be done with hand or power drills. Choice of the two methods will depend on such factors as the thickness of the ledge, availability and cost of labor, the quality of the stone, and the capacity of the pulverizing machinery. Two inexperienced men with hand drills will drill a hole 1 inch in diameter in limestone at a rate of 1 foot in 40 minutes. A churn drill, a piece of drill steel 5 to 6 feet long, operated by one man, will drill faster than a hand drill. After a hole is started with a hand drill the churn drill is put in and is lifted and dropped.

Where quarry operations are on a large scale and the limestone formation is horizontal, or nearly so, well drills are used. Where operations do not warrant so large an investment, jackhammer drills are usually sufficient. These drills are operated by means of compressed air, electricity, or steam. If the grinding machinery is operated with steam, it is usually most convenient to use the steam jackhammer. Disadvantages of steam are the high heat loss by radiation and condensation, and the possibility of damage to steam pipes when the blasts are fired. Electricity has the advantage of being readily available at all times and the equipment is easy to move. Compressed air has the advantage of portability, not only in the quarry but from one quarry to another. The initial cost of power-drill equipment is relatively high for a small quarry operating only 6 to 8 months a year. In some localities compressors and jackhammers may be rented by the day.

A steam drill in a small quarry should average 60 feet or more of hole per 10-hour day. It is said that machine drilling is 5 to 15 times as fast as hand drilling and that in limestone there are records of instances where a foot has been drilled in 3 minutes. At an In-

diana quarry where drilling was done with jackhammer drills using 1-inch hexagonal steel and six-point star bits, with one man doing all the drilling, the speed was 17 feet per hour. The holes were 10 feet deep, 2 inches in diameter at the top, and 1½ inches at the bottom. In another instance on medium-hard limestone, the drilling rate with a jackhammer was 120 feet per day.

The cost of machine drilling, not including depreciation on equipment, is usually much less than that of hand drilling. In several small quarry operations fostered by the State Rural Rehabilitation Corporation of West Virginia, the cost of gas, oil, and labor on compressed-air drilling operations varied from 2.8 cents to 3.5 cents a ton of ground limestone. The interest and depreciation costs for the compressor, for a ton of output, may vary widely depending on the amount of work done. Where the machine is in constant use the operation cost, not including depreciation, may be only a fraction of a cent a ton.

The spacing and depth of drill holes will vary somewhat in different quarries, depending on the height of the quarry face and the quality of the rock. Where the quarry face is 12 to 15 feet high the holes are drilled from 8 to 10 feet back from the face and from 6 to 8 feet apart. In some cases it may be advantageous to drill two rows of holes, staggering the second row and firing both at once. In a quarry near Milltown, Ind., in drilling operations on a 9-foot bench, the holes were drilled 10 feet deep, 6 feet back from the quarry face, and 6 feet apart. In a West Virginia quarry where the face was 30 feet high the holes were drilled 10 feet back from the quarry face and 10 feet apart. The best spacing for each quarry and sometimes for different parts of the same quarry must be determined by trial. If the quarry floor is to be kept level, care must be taken to drill holes to the same level, which should be slightly lower than the quarry floor. The correct depth can be determined after trial. Notes of conditions found when drilling are often of value when the holes are loaded.

Figure 1 shows the start of the drilling operations in a small quarry. The gasoline-driven air compressor is shown at the right of the picture.

BLASTING

After the holes have been drilled they should be tested before being loaded, to be certain that they are open to permit the free passage of the explosive.

The type of explosive to use is determined by the conditions in each quarry. Where the drill holes fill or partially fill with water, or where the stone is to be well shattered, it is advisable to use gelatin dynamite. Where the holes are merely damp, a moisture-resistant explosive should be used. In few cases will it be advisable to use an explosive less than 40 percent strength. The most commonly used size of dynamite cartridge is 1¼ by 8 inches. A ⅞- by 8-inch cartridge is also manufactured which may be used where the drill hole is less than 1½ inches in diameter. Large cartridges for drill holes 5⅝ inches in diameter or larger, used in large quarry operations, are on the market.

The amount of explosive necessary to blast down the rock will vary in the different formations. Where the limestone has been ap-

preciably weathered the quantity of explosive necessary may be small. Where weathering has not been severe and the stone is tough, much more explosive may be needed, particularly when good breakage is desired. Since the breakage per pound of explosive varies from 3 to 6 tons, a common method is to assume a breakage of 3 or 4 tons per pound and load at that rate. After a number of trials the rate of loading for a particular formation may be determined. These trials will also help to determine the correct spacing for drill holes. Another method suggested is to fill the drill holes at least half full with explosive. In a West Virginia small quarry operation the loading rate is 0.4 pound per 1½ tons of stone broken down, or at the rate of 3¾ tons per pound.

FIGURE 1.—Drilling holes in preparation for blasting. The overburden in the middle foreground is to be hauled away and used for highway fill.

In some quarries the drill holes are "sprung" so they may receive more explosive; that is, a small quantity of explosive is first used and the lower portion of the hole is then enlarged sufficiently to hold the necessary quantity. In bore holes of the size made by jackhammers, 2½-inch diameter or smaller, not more than six or eight 1¼- by 8-inch cartridges of dynamite should be exploded at one time because a heavier charge may cause the bore hole to cave or close up. Where slight caving occurs with light charges the bore hole can usually be opened up with a drill or steel bar. The effect of the explosions is to increase the bore hole in depth and diameter. The approximate size of the cavity can be estimated by dropping a short bar of wood attached to a rope. In making springing shots very little "stemming" (earthy material free of grit or stone) should be used, and there should be a sufficient interval between shots to permit of the cooling of the rock to avoid premature explosions when subsequent charges are loaded.

When the sprung holes are finally loaded for blasting, the explosive should be tamped firmly with a wooden tamping stick so there are no air spaces, since close confinement of the explosive increases its effectiveness. The escape of explosive gases through open seams,

which reduces or nullifies the effectiveness of the explosive, may be avoided by dividing the charge. This is done by loading to a point below the seam, priming with an electric cap, and filling with well-packed earth to a point above the seam after which the loading of the hole is completed and primed with an electric cap. The use of electric caps permits simultaneous explosion of the separated parts of the charge. Caps and fuse cannot be used for this kind of shot since two charges primed with cap and fuse cannot be exploded simultaneously.

SECONDARY BLASTING

Occasionally masses of rock loosened by the first or primary blast are found to be too large to handle. They may be broken down with explosives by either blockholing or mudcapping, methods known as secondary blasting.

Blockholing consists in drilling a hole in the rock and loading it with a small charge of explosives. The depth of the hole for best results depends somewhat on the quality of the stone. As a trial it will be advisable to drill the hole to a depth of one-half the thickness of the stone. The quantity of explosive necessary to break a stone will depend on the size, toughness, and condition of the stone; that is, whether it was cracked as a result of the primary blast. For a trial shot the load suggested is one-half pound or less per cubic yard of stone. The amount of shattering will determine the accuracy of the load, and the succeeding loads should be decreased or increased accordingly. In loading, the explosive may be left in the wrapper, or it may be removed and poured into the hole. Where only a part of a cartridge is to be used, the wrapper only should be cut; the cut should not be made through the explosive nor should the cartridge be broken without cutting the wrapper. Where the explosive is removed from the wrapper and packed in the hole the wrapper should be packed over the charge after the cap has been inserted.

In mudcapping, the explosive is held against the boulder to be broken by a 6- or 8-inch layer of well-packed wet earth. As the explosion of dynamite has the same effect as the blow of a hammer, a common rule is to place the charge at the weakest point. Concave surfaces are favorable places for loading because they help to confine the explosive gases, whereas convex or rounded surfaces have a tendency to dissipate them. The explosive may be removed from the wrapper or used in the stick form. If removed from the wrapper it should be thoroughly packed and the blasting cap imbedded in it before the mud is applied.

The quantity of explosive necessary can be determined after a few trials. A rule of thumb frequently used is to load at the rate of 1½ pounds of explosive per cubic yard of stone. Since the wet earth confines the gases for only a short time a high-velocity explosive is more effective than a low-velocity one. The charge necessary for a mudcap shot is appreciably greater than that needed for blockholing. Where jackhammers are available for the drilling, the blockhole method is better.

For blockholing and for mudcapping either electric or common fuse caps may be used as detonators, but the electric method of firing avoids hangfires, which are always dangerous, and the consequent loss of time waiting for the charge to explode.

SAFETY PRECAUTIONS

Dynamite and other high explosives and blasting caps are so dangerous, particularly in the hands of inexpert people, that they should not be handled or used except under the supervision of an experienced person known to be careful. Detailed instructions to meet all conditions and covering all methods and materials can not be given in this bulletin; but any one who plans to do blasting should obtain a handbook of instructions such as are put out by manufacturers of explosives. Even with the best of instructions safety demands the presence of an experienced man to supervise the job.

Explosives should be stored in well protected magazines, the caps stored separately from the dynamite, and unauthorized persons should be kept strictly away.

Caps should be carried in a box designed for the purpose—never in the pocket.

Straight dynamite is too sensitive to friction and impact for quarry blasting. Ammonia dynamite is less dangerous and less expensive. Gelatin dynamite is less easily set off by friction and not so liable to crumble and be spilled on the rock around bore holes.

It is highly desirable to fire charges with a blasting machine or electric detonator rather than with fuses, which frequently cause hangfires. A large percentage of blasting accidents are the result of hangfires. Electric blasting caps eliminate this danger. Since the number of charges to be fired at one time will be small, a blasting machine will furnish enough current. All charges should be connected in series, which reduces the possibilities of misfires and the consequent danger that quarrymen will hit a charge with a pick or other tool.

Tamping of charges should always be done with a wooden tamper with no metal on it.

Never handle explosives roughly or slide packages over each other or along the floor. Always know where explosives are, and be sure that the place is safe from tampering, fire, or from rock fragments thrown in blasting.

One person should have absolute charge of the blasting and care of the materials. When blasts are about to be fired all workmen should be required to respond to a signal so the blaster may be sure they know a charge is to be fired and that they are far enough away.

In limestone grinding, discussed in the next section, precautions should be taken to prevent injuries to workers. Each man should be careful for himself and do all possible to protect others. Exposed moving parts of machinery liable to cause injury should be covered or shut off from close approach.

If all equipment and tools are kept in good condition, danger of accidents will be less.

Before using explosives or operating grinding machines, find out about State and local laws and regulations bearing on such operations.

GRINDING

In grinding agricultural limestone a combination crusher and pulverizer or pulverizer alone may be used. Each has advantages and disadvantages.

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The jaw type of crusher is most common for primary crushing in small operations. Where it is operated before the pulverizer, the quarried stone need not be so small as would be necessary if the stone were fed directly to the pulverizer. In working formations of tough limestone where the strata are thick or the lines of cleavage are not distinct, the use of a crusher may save in drilling and explosives cost because the stone need not be shattered so much as for feeding to the pulverizer. Some labor also may be saved. On the other hand, the purchase of a crusher will increase the machinery investment and the overhead costs, and power will be required for operation. If both crusher and pulverizer are to be used, they should have about the same capacity.

In weathered limestone good breakage is possible with little or no explosive, and a crusher is not needed. With a little sledge-hammer work the stone can be fed directly to the pulverizer. Pulverizers, depending on size, will take stones from the size of a brick to stones weighing 75 pounds or more. Feeding quantities of small stones to the pulverizer may clog it, while continuous feeding of big ones places an excessive strain on the machine.

The hammer mill is the type of portable pulverizer most used. It ranges in price from $500 to $3,000 or more, and in capacity from 3 to 12 tons per hour. Fineness of grinding, quality of stone, and the power used, affect the rate of grinding. The capacity of the machine and the amount of equipment purchased should be based on the number of farmers in the cooperative, or on the probable demand from the community for ground limestone from the quarry. It would not be advisable to buy expensive equipment if the demand is only sufficient to keep it in operation a short time each year.

The fineness to which a pulverizer may grind lime is limited by the spacing of the screen bars. It may vary from the maximum that will pass the screen bar to very fine. Since the fineness is also determined somewhat by the velocity at which the hammers revolve, it is advisable to apply sufficient power to maintain the speed recommended by the manufacturer, which is also necessary if the productive capacity of the machine is to be maintained. Speed much greater than that recommended by the manufacturer, however, is dangerous.

Power is generally obtained from a tractor. This is convenient because the tractor may be also used to draw the pulverizer from one location to another and may readily be obtained on a rental basis. Stationary engines are sometimes used, and in some localities light steam boilers and engines in good condition that have been displaced by gasoline motors may be purchased at a reasonable price. Before purchasing steam equipment, however, State laws governing its operation should be learned so that all requirements, such as hiring a licensed engineer, are fulfilled. In any case the boiler should be inspected by a competent person.

Grinding equipment may be located at such distance from the quarry that stone may be taken to it by means of wheelbarrows, by a quarry car, or by trucks or wagons. The distance between the quarry and the pulverizer should be kept as short as feasible. Where the distance is short the principal expense will be for wheelbarrows and labor. For longer distances there will be the cost of operating a

small railroad car or truck, but fewer men will be required and the pulverizer will not need to be moved so frequently. Where trucks or wagons are used, the hauling distance may be somewhat greater than is practicable for wheelbarrows or quarry car.

It is possible to so regulate grinding that no storage is necessary, but it is convenient to have at least a small storage bin for the ground limestone. This may be of the temporary, transportable type shown in figure 2, or all-metal bins may be bought. In all but the simplest plants, one or more elevators are necessary to facilitate loading or storage.

FIGURE 2.—Temporary bin with pulverizer. Note the cloth hung on the side to prevent the fine limestone from being blown by the wind.

MAINTENANCE OF EQUIPMENT

Because of the heavy stresses on the machinery the wear and tear is necessarily rather high. The wear is greatest on the hammers of the pulverizer because they are in almost constant contact with the stone. While the extent of wear depends largely on the quantity of stone pulverized, the quality is also a factor. The presence of abrasive materials in the stone will materially increase the rate of wear, particularly of the hammers. Under average conditions, from 1,800 to 2,000 tons of limestone can be ground with one set of reversible hammers. Hammers range in price from $20 a set, up, depending on the machine. Under average conditions screen bars will wear approximately two to three times as long as hammers, while liners and breaker plates may wear from five to six times longer. Records kept by the Kentucky Department of Agriculture indicate a maintenance cost for portable pulverizers of approximately 3 cents per ton of ground limestone, but the general average probably is about 4 to 5 cents per ton.

SUGGESTED PROCEDURE PRELIMINARY TO FARM LIMESTONE GRINDING

The general procedure to be followed on a farm for the purpose of producing agricultural lime for a group of farmers is: (1) Deter-

mine the amount of lime required annually. (2) Determine the probable saving by comparing the cost of home-produced lime and the cost of lime obtained from commercial producers, taking into consideration the transportation charges. (3) Determine the extent of the limestone formation on the farm by boring, probing, or digging. (4) Determine the quality of the limestone by chemical analysis. State agricultural colleges have facilities for doing this work. (5) Get prices on limestone-grinding equipment. (6) Before buying an outfit try to have a demonstration of how it will work with the particular stone to be crushed. (7) Figure costs of producing ground limestone of the fineness recommended by the State agricultural college.

To determine the cost of producing ground limestone such factors as cost of equipment, depreciation, interest, labor, and other items should be considered. For example:

Limestone formation	8 feet thick.	
Overburden	1 foot thick.	
Ground limestone (annual demand)	140 tons.	
Volume of overburden to be removed	212.5 cubic feet.	
Volume of rock to be ground, approximately	1,700 cubic feet.	
Time required to strip the quarry, 1 man and 2 horses	3.5 days.	
Cost of stripping (3.5×$4—cost of team and labor[1])	$14.	
Number of men for quarrying and pulverizing	5.	
Cost of pulverizer with 2 ton per hour capacity	$625.	
Estimated life	20 years.	
Hours worked annually	70.	
Fixed charges:	*Per hour*	*Per ton*
Depreciation (20 years of life, estimated)	$0.41	
Interest (average annual investment[2])	.22	
Total	0.63	$0.32
Other costs:		
Tractor	.75	.38
Labor, 5 men at 25 cents per hour	1.25	.63
Repairs at 4 cents per ton	.08	.04
Stripping quarry	.20	.10
Royalty	.10	.05
Total	3.01	1.52

[1] Man labor, 20 cents an hour; horse labor, 20 cents an hour.

[2] Average annual investment $= \frac{\text{first cost} \times (\text{years of service} + 1)}{\text{years of service} \times 2}$

The cost of the pulverizer equipped with wheels and elevator is the average price of a number on the market. About 18 horsepower is required to operate the pulverizer; this can be furnished by the average farm tractor equipped for belt-power work. This additional work helps to reduce the operating cost of the tractor for both the farm and the pulverizing work.

It will be noted that the calculated cost per hour of producing ground limestone, except for royalty and repairs, will remain the same regardless of the quantity of ground limestone produced. It is therefore evident that the planned rate of production must be maintained if the cost is to be held within the estimate. If production per day can be increased beyond the point originally planned, the cost per ton will be less, or the same result will be obtained if the plant is operated for a longer period annually. Where larger operations

are under consideration all factors involved must be studied carefully. While larger operations will permit lower cost production when carried on under the proper conditions and in an efficient manner, it is also true that the losses will be greater when operations are carried on under adverse conditions or in an inefficient manner.

The ownership of units may be of different kinds. The machinery may be purchased by a group of farmers and operated at one quarry, or it may be operated on the premises of the different members of the group where limestone is available. In either case the members of the group may comprise the operating crew. The ownership may also be held by a cooperative organization which operates the equipment during the lime-grinding season, and the labor employed may or may not be farmer members. Still other systems of ownership and operation may be adaptable to a given locality.

BURNING

Burned limestone is used extensively on farms and is obtained by heating or burning high-calcium or magnesium limestone to drive off carbon dioxide gas. The addition of water to the portion remaining changes it to slacked lime. Under favorable conditions the farmer may burn limestone economically for his own use. While the cost of burning adds considerably to that of the raw limestone, it gives a product with about twice the neutralizing power of the original stone.

When limestone is burned, carbon dioxide is driven off, and calcium oxide or calcium and magnesium oxides remain. The quality of the lime depends on the quality of the stone used and the care taken in burning it. Limestone can be burned by one farmer or by a group of farmers with little or no investment in equipment, since the only requirements are labor, low-cost fuel, and low-cost, good-quality limestone.

The amount of heat required to burn limestone depends on its character and varies from 1,400° to 2,200° F. Greater heat is usually required for calcium limestone than for magnesium limestone. Where such impurities as silica, alumina, and iron are present, the temperature must be kept below their melting points to prevent the formation of slag and the making of "dead burnt" or "overburnt" lime. About 2 percent of silica will not affect the burning of the stone, but the alumina and iron content should not exceed ½ to 1 percent. Less heat is required to burn a dense, fine-grain stone than one which is coarsely crystalline and porous. In burning, a high temperature may be used for a short time or a lower temperature for a longer time. The more nearly the amount of heat used approaches the minimum required, the better the quality of the lime.

Temperature measurements made of the heat developed while a lime stack in Pennsylvania was being burned indicated that on the sixth day of burning the temperature near the top of the stack was 518° F. and the highest temperature, 840°, was at the bottom of the stack near the outside. Seven days later, the temperature at its highest intensity having become well distributed throughout the stack, the color of the mass for a distance of several feet inward was a

bright cherry red, indicating that the temperature had been about 1,500°. The analysis of the stone burned was:

	Percent
Carbonate of lime	51.72
Carbonate of magnesia	41.75
Iron and aluminum oxide	1.06
Sand, clay, etc	5.02
Undetermined	.45
	100.00

In burning limestone for agricultural uses either the stack or kiln method may be used. Both methods have strong advocates, but there seems to be little reason, except personal preference, for the selection of one method over the other under normal conditions.

STACK METHOD

A method used in Kentucky (fig. 3) is to first lay down green logs about 1 foot in diameter and 16 feet long with 2-foot spaces between them, so as to make a base 12 to 16 feet wide. If full-length logs are not available, shorter logs, placed end to end to make up the

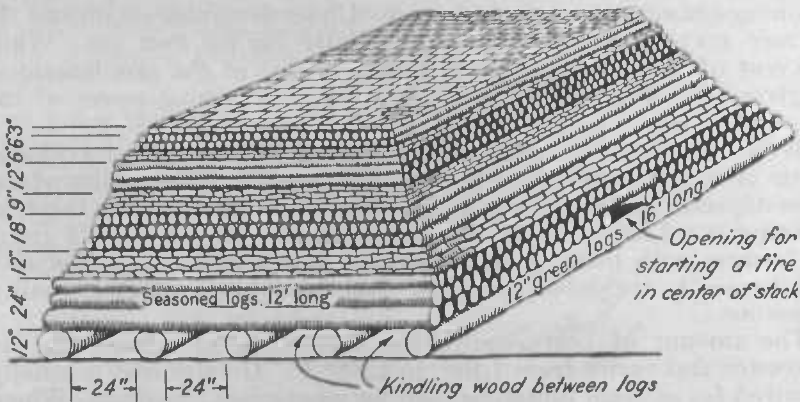

FIGURE 3.—A method used in Kentucky for laying a lime stack.

necessary length, may be used. The 2-foot spaces are filled with dry wood for starting the fire. Only green logs are used in the foundation because they do not burn readily and will hold the lime stack off the ground so a better draft will be obtained.

Across the foundation logs well-seasoned logs, as large as can be obtained, are laid to a thickness of 2 feet. The logs are placed as close together as possible. A space 3 feet square is left in the center of this layer and filled with well-dried kindling wood. A space 20 inches wide is left through the 16-foot dimension of the stack to permit igniting the wood in the center since it should burn from the center outward. This 20-inch space is omitted in the succeeding layer.

Stones varying in size from 1 to 6 inches in diameter are piled on the layer of seasoned wood to a thickness of 1 foot, or one-half the thickness of the logs beneath. As more layers of stone and wood are added, each succeeding layer of wood is decreased 6 inches in thickness and 2 feet in width from the layer preceding, piled at right

angles to it, and covered with stone to a depth one-half the thickness of the logs beneath. The stack may be 8 feet high. The fire is started by igniting the dry wood in the 2-foot spaces in the foundation and in the 3-foot square space at the center of the second layer.

A stack built in Pennsylvania had first a lower layer of apple wood, trunks and limbs, arranged radially from the center with narrow air spaces between the pieces to give draft. Over the apple wood a layer of old chestnut fence rails was laid, and over these three wagonloads of dry corncobs were evenly spread. The diameter of this foundation was 32 feet. About the center of the stack a layer of white pine kindling 3.5 feet in diameter and 15 inches deep was spread, and in the midst of this kindling a flue made from 6-inch chestnut boards was placed. The flue was held in place by wooden braces.

The stone was laid in successive layers, the size and thickness of the stone increasing with each layer. The thickness of the first layer was 3 inches, and the thickness increased approximately 2 inches with each layer to and including the fifth; from there on, approximately the same thickness was maintained for the remaining layers except the tenth (the last), which was made 2 inches thicker. The stone in the first layer measured 3 inches in diameter; that in the second and third layers, 4 inches; that in the fifth and sixth layers, 6 inches; and in the remaining four, approximately 7 inches. Each successive layer was covered with just enough coal to form a continuous black surface.

The lowest layer was 30 feet in diameter so that the wood, or foundation, projected 1 foot around the entire stack. The higher layers were of lessening diameter so that when the stack was completed the top was about 10 feet in diameter, and the vertical height was 10 feet. When the final layer was completed, coal was banked on the sides of the stack, and over this was placed a well-firmed layer of earth 10 inches thick. No earth was packed over the wooden foundation layer.

The kindling at the bottom of the flue was ignited after being wet with kerosene. The flue was left open 6 hours; after that it was covered with a flat stone over which earth was thrown. The uncovered wood foundation layer admitted sufficient air to keep the fire burning. When the foundation layer had completely burned, earth was thrown around the base of the stack to cut off the bottom draft. All openings which appeared in the soil covering were promptly closed. The total actual burning time was 11 days, after which the stack slowly cooled for 9 days, when the earthen cover was removed and the heap exposed to further cooling for 2 days.

The total amount of limestone burned was 307,964 pounds, and the total weight of the lime, including coal ashes, was 188,760 pounds. Deducting 4,000 pounds for the estimated weight of the coal ashes, there was 184,760 pounds net of lime. The cost of production was 9.2 cents a bushel, or $2.33 a ton of 2,000 pounds, when man labor was 17.5 cents an hour, team work 40 cents an hour and coal $2.60 a long ton (2,240 pounds) f. o. b. freight station. There was no cost for quarrying, the stone having been delivered at the burning site; however, it was necessary to break the stone further to make it of suitable size for burning.

In West Virginia a method similar to that in Pennsylvania is employed. Approximately 3 cords of seasoned wood are used to make

the base of a 100-ton stack. In the center a large log is placed upright, and from it in the base four logs of 2-foot diameter are placed radially, at right angles to each other. The openings left by these logs when burned provide draft until the firing has been properly distributed, after which one or more may be stopped up. The stone is broken to a size not to exceed 6 by 8 by 10 inches, placed in layers 12 to 14 inches thick, and each layer covered with about 3 inches of coal. Alternating layers of stone and coal are placed until the stack reaches a height of 10 feet. The entire stack is covered with earth 2 feet thick at the base and gradually tapering to 1 foot at the top.

After the stack has burned for 3 or 4 days, or when the stone becomes a dull red, all openings are sealed. As the burning progresses, all crevices or openings which develop are covered with earth. The average burning time is 9 to 11 days and the cooling time 2 weeks unless there is rain, in which case the cooling time is less. To examine the progress of burning, a hole is shoveled in the clay coating. During the early stages of heating the stone appears to be a dull red and later, as calcination takes place, the color changes to white, with the unburned core or bone in the center of the lump appearing violet red in contrast to the white heat of calcined stone. When the violet-red color has disappeared, complete calcination has occurred.

These stacks are built near the quarry. No explosive is necessary in quarrying because of the weathered condition of the stone. In constructing a stack 10 feet high five men can place 45 tons of prepared stone and the necessary coal per day up to 6 feet in height. Above 6 feet the tonnage per day decreases 50 percent. To complete a 100-ton stack requires the labor of five men for 3 days after the rock has been prepared, and an additional day for five men is required for clay banking and firing. It is advisable, however, that a stack of 100 tons or more be built up to a height of 10 feet, and when possible 15 feet, in order to secure efficient and complete combustion by utilizing the hot gases that pass upward through the stack. One ton of slack, or fine coal, is required to burn 3 tons of raw limestone to produce 3,540 pounds of quicklime, or 5,310 pounds of hydrated lime. If higher-grade coal is used, 1 ton of fuel will calcine 4 tons of raw stone.

KILN METHOD

A method of kiln construction used in Virginia (fig. 4) is as follows: A location close to the quarry is selected, preferably on the side of a hill. An excavation is made 10 feet into the hill and to a depth of 7 feet. The width of the kiln is 8 feet at its greatest breadth, sloping gently downward toward the front on the bottom. A trench 18 inches wide and 12 inches deep is dug through the center at the base. Across this trench pieces of old iron castings are placed to serve as a grate. The front and side walls of the kiln are built like a retaining wall. Sometimes the rear walls are built of rock, but usually the sides of the hill answer the purpose. The general plan of the kiln is oval, both at the base and top.

Over the grate in the center is placed a layer of coal lumps too large to pass through the opening. On top of this is placed limestone rock, which may vary from 6 inches to 12 inches in diameter. The kiln is then filled by placing alternate layers of coal and rock. An opening large enough to serve as a flue is left in the rear at

the top. When the kiln is filled, it is covered with a layer of flat rocks, and the front is closed with rock and sealed with mud. Sufficient kindling is placed in the trench to ignite the coal. The fire usually burns for 2 to 3 days, and 3 to 5 days are allowed for cooling.

The services of one man from 8 to 10 days are required to build and operate the kiln. In a kiln of this size 100 bushels of coal are used with 300 bushels of limestone.

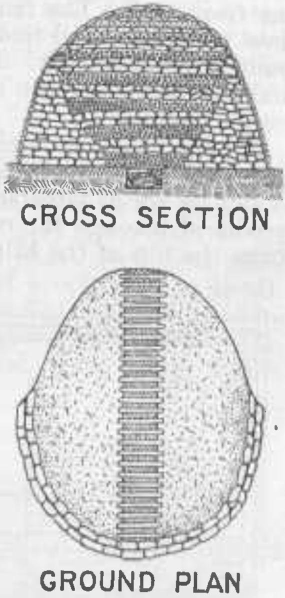

FIGURE 4.—Cross section and plan of lime kiln used in Virginia.

A method used in Kentucky is to excavate 15 feet into a hill so that the top of the bank in the rear is 6 to 10 feet above the bottom of the pit. The back and sides are made straight and vertical and the bottom level.

The foundation for the "eyes," or fireboxes, is made by laying large flat limestones in the bottom of the pit according to the dimensions shown in figure 5. When the foundation has been laid, construction of the eyes is started at the rear and completed at the front (fig. 5). Smooth, flat stones are used for this purpose. The eyes, which take the form of a triangle 36 inches high, are formed by extending each stone 2 or 3 inches over the one below. Instead of using a keystone, a flat stone about 6 inches thick and 2 feet long is laid across the gap at the top. All joints should be broken, and occasionally a long stone is placed across the span between the eyes to tie them together.

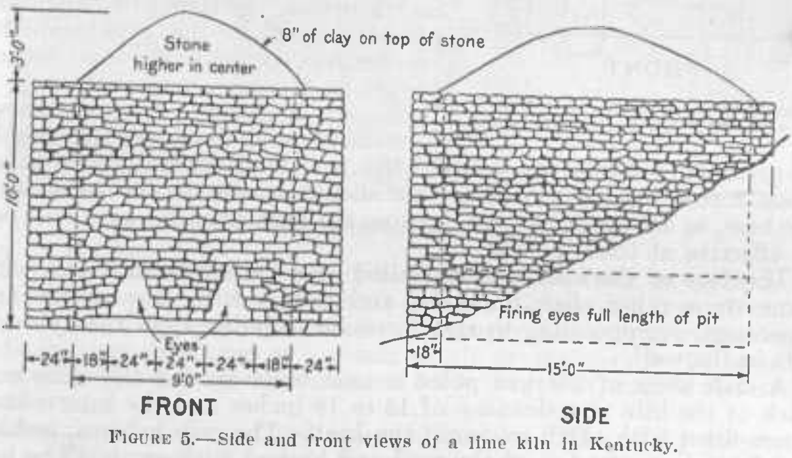

FIGURE 5.—Side and front views of a lime kiln in Kentucky.

After the eyes are completed and before the outside walls are built, the pit is filled to the top with broken stones, the heavier pieces of which are placed directly over the eyes and the smaller at the top of

the kiln. Filling of the kiln with broken stone is continued as the walls are built.

The front is built to a height of 10 feet. The side walls are built on the ground at the outside of the pit, extending up the slope from the front wall. The front and side walls should be of equal height, level at the top, and tied securely at the corners. A back wall is not built unless necessary. The outside walls are plastered with wet clay and the top of the kiln covered with at least 8 inches of wet earth to retain the heat.

For use in firing, well-seasoned wood is essential. A slow fire is first kept for 12 to 14 hours to season the stone, after which the fire is kept as hot as possible. A flue is not necessary as sufficient draft is produced through the rock and earth. A heavy black smoke escapes from the top of the kiln while the stone is burning. After this has ceased a crowbar is driven into the top to determine when burning is complete. Seven days and nights of continuous burning is required for the average kiln.

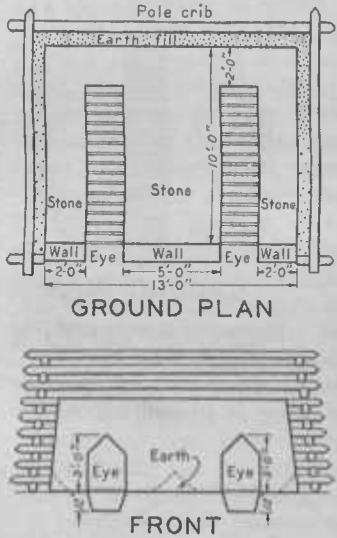

FIGURE 6.—Ground plan and front view of a lime kiln in Pennsylvania.

A method of kiln burning somewhat similar to that just described is used in Pennsylvania. A rectangle 10 by 13 feet is first laid out. Two eyes are constructed, as previously described, under each of which has been dug an ash pit 16 inches wide and 12 inches deep. The eyes, across which irons are laid to act as a grate, are 2 feet wide and 3 feet high. When the eyes have been completed, the kiln is built up solidly to a height of 8 or 10 feet with stone 4 to 8 inches in size, the larger of which are placed closest to the eyes and the smaller farther away; the top 6 inches of fill is of stone not much over 2 inches in diameter. The thickness of stone between the eyes and the side and rear walls should not exceed 2 feet, and fillets of earth or of other stone 1 foot high and 1 foot wide should be put in the corners of the base, as shown in figure 6, because the heat from the eyes will not be effective at those points.

The face of the kiln is next walled up to a height of 5 feet with some stone other than limestone and bound with clay or mortar. Openings corresponding to and sometimes smaller than the eyes are left in the wall.

A crib work of notched poles is next built around the sides and back of the kiln at a distance of 15 to 18 inches and the intervening space filled with earth to retain the heat. The crib is continued on the face above the top of the wall and backed with earth. The top is left open.

Fires are kindled on the grates in the eyes and fed with well-seasoned wood for from 3 to 5 days and nights, depending on the wood, draft, and the weather. The eyes are closed with sheet iron when not being fired, but draft must be furnished through the ash-pit. When the burning is completed and the kiln has cooled, the lime is taken out from the rear after the removal of the poles and earth. The kiln may then be built up again and fired.

MARL

There are several types of marl. That deposited in low depressions is usually the most costly to dig. In marshy locations the deposit may be covered with a layer of muck or peat varying in thickness from a few inches to several feet, and water may cover part or all of the site. In one county in Michigan the State geological marl survey showed the ratio of average depth of overburden to depth of marl for beds workable by hand to be 1 to 6½, and for deposits workable with power equipment the ratio is given as 1 to 8¾. The surface is sometimes covered with tough marsh grass, which makes the removal of overburden difficult.

FIGURE 7.—Digging lowland marl in a dry season.

Saturated marl weighs about 50 percent more than an equal volume of water; when the marl is air-dried, a considerable loss of water as well as of volume takes place. Measurements of piles excavated indicate that shrinkage as a result of air drying may be 25 percent or more. The unit of measurement for this type of marl is the cubic yard.

Marl is soft, spongy, and extremely sticky. The sticky property has made its excavation with the slip scraper and other small equipment practically impossible, but it can be readily handled by power machinery.

In seasons of drought, marl deposited in low marsh areas may be dug by hand, as shown in figure 7. In 1931, owing to lack of rainfall, about 80 percent of the marl pits in Michigan were worked by hand. When wet marl is soft the shovelers are likely to sink into it somewhat. Under these conditions shoveling is difficult and slow. It has been estimated that in lowland marl a man can dig an average of 0.4 cubic yard per hour.

More lowland marl is dug with machinery than by hand. Some marl has been dug by the larger commercial outfits on a per yard basis, but this is feasible only where considerable quantities are dug. In the winter of 1934–35 a number of commercial units dug lowland marl at prices from 8 to 20 cents per cubic yard. In normal times the contract price would probably be nearer 50 cents per cubic yard for large quantities.

Because of the smallness of the operation, farmers who have marl deposits desire a small, low-cost excavating unit. Such a unit has been designed by the Agricultural Engineering Division of Michigan State College of Agriculture, the important feature of which is a ¼-yard bucket especially constructed to dig marl. This unit is a slack-line cableway rather than a dragline, and the power used may be a team or tractor. The estimated capacity of this unit is 40 cubic yards per day at a cost of 15 cents to 25 cents per cubic yard.

As an illustration of marl-digging costs where equipment must be used to dig it out of a lake bed or other wet location, assume that the type of equipment to be used is that developed for the purpose in Michigan.

Cost of the marl-digging equipment including the Musselman bucket	$210.
Estimated life	10 years.
Time worked annually	120 hours.
Quantity dug per hour	3 cubic yards.

	Per hour operation	*Per cubic yard*
Fixed charges:		
Depreciation (10-year life, estimated)	$0.17½	$0.06
Interest at 7 percent=$9.09 per year	.07	.02
Operating cost:		
Labor, 2 men at 20 cents per hour	.40	.13
Team, 4 horses, at 10 cents per hour	.40	.13
Removing overburden	.22½	.08
Royalty	.60	.20
Repairs (estimated)	.06	.02
Total	1.93	.64

The item of 2 cents per cubic yard for repairs, while estimated, is believed to be ample. It is also probable that the life of the equipment is greater than indicated since the wear and tear on it is small as compared to that on equipment for crushing and pulverizing limestone. The cost per hour of digging marl, except for royalty and repairs, remains the same regardless of the quantity dug while the cost per cubic yard will vary with the quantity dug per hour. As with the lime-grinding operations the greater the production per hour the lesser the cost per unit of measure and conversely the lesser the production per hour the greater the cost per unit of measure. It is

therefore important that the production be maintained at as high a rate as possible if the cost is to be kept low.

Upland marls are generally dug by hand, and the rate of digging is about 1 to 1½ cubic yards per man-hour. In some cases these marls contain considerable moisture and in others little if any. In the former case digging may be started with very little preparatory work except for the removal of the overburden, while in the latter the removal of overburden must be followed by plowing to loosen the marl. In Kentucky the suggested procedure is to remove the overburden covering the marl bed to the greatest practical width and length to provide for future development. Plowing, which is done across the slope, should be done shortly before loading because the marl can be handled better then than later when it has absorbed moisture. The use of a portable chute is also recommended because it is the most efficient method of loading marl; the cost of construction is low; the chute is easily moved from one bed to another, does not have to be adjusted to the height of wagon or spreader, and can be easily moved to various parts of the marl bed to save labor in loading. The cost of excavating and spreading marl of this type is about 50 cents per ton. It is estimated that one man can dig and spread 12 tons of marl a day if the hauling distance is not more than one-fourth mile.

In one West Virginia project upland marl is dug by means of a gasoline shovel, and the larger pieces are screened out. Shovel rental is $1.50 an hour including gas, oil, and operator. Under favorable conditions this shovel will handle 12 tons an hour. The cost of shoveling is approximately 15 cents and the screening costs approximately 11 cents per cubic yard. These costs vary somewhat in different locations.

SPREADING LIME

The farmer may haul the lime in his own truck, or he may arrange with a truck owner to do the hauling or to do both the hauling and the spreading. In the last case the farmer is relieved of a task usually distasteful, requiring considerable time which could be used to good advantage in doing other farm work, particularly in the rush season. It is probable that a truck driver experienced in this sort of work will spread the desired quantity per acre more uniformly over the field than would the average farmer who does this work only now and then. Drivers who haul lime say that a truck having dual wheels can spread a 6-ton load on plowed ground that is not too wet. They also report that it requires nearly as much time to unload the lime at one point on the farm as to spread it on the field.

The spreaders used range from those of a home-made type costing only a few dollars to manufactured types, such as that shown in figure 8, costing up to $350. The number of men required to spread lime ranges from one to three, depending on the spreader, including the driver of the truck or wagon.

FIGURE 8.—A light lime spreader attached to a truck.

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